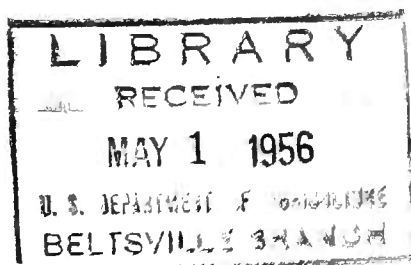# Methods for Evaluating
IRRIGATION
SYSTEMS

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Soil Conservation Service

UNITED STATES DEPARTMENT OF AGRICULTURE

Contents

Methods for Evaluating
IRRIGATION SYSTEMS

By Wayne D. Criddle, Sterling Davis, Claude H. Pair, and Dell G. Shockley, Irrigation Engineers [1]

MANY IRRIGATION SYSTEMS, both surface and sprinkler, are poorly adapted to the soils and topography. Intake rates and water-holding capacities of the soils often were not known before a field was laid out for irrigation. Frequently, little effort was made to learn how much water could be run in each furrow or border strip without causing soil erosion. The length of irrigation run needed for proper distribution of moisture in the root zone of the crop seldom was determined. Often, sprinkler irrigation systems failed to apply water in accordance with soil characteristics and crop needs. Improper operation of well-designed irrigation systems also has wasted water, damaged land, and reduced production and net income.

Excessive irrigation wastes not only water. It also leaches water-soluble nutrients beyond the plants' reach. Too-heavy irrigation on higher land often causes waterlogging of rich, lower lying lands. To correct this usually requires installing a costly system of drains as well as reclamation. On a field being irrigated, by surface or gravity methods, inefficient use of irrigation water usually shows up in poor yields at the upper and lower parts. This is because the upper part lost nutrients by erosion and leaching and was kept too wet for good growth, while the lower part received too little water.

How to apply irrigation water to crops without eroding soil is a problem. Improvement in its fertility and structure usually enables soil to take in water faster. As the intake rate increases, larger streams of water must be delivered to the furrows and borders to get uniform irrigation. Even though erodibility may be decreased by good soil management, the effect of the larger streams may more than offset any such gain.

Irrigation engineers, Soil Conservation Service technicians, and other professional people working in irrigation should find the evaluation methods described here useful in helping farmers attain greater efficiency in irrigation. These evaluations will also lead to better design criteria for local soils, crops, and climatic conditions.

Furrow- and border-evaluation trials by the Soil Conservation Service showed the need to control irrigation streams, especially where water is delivered through large, open ditches in which the flow may fluctuate. Such fluctuations can be controlled rather simply. The method suggested here uses relatively large overflow-type controls and submerged orifice-type controls of small capacity.

Discharge over the overflow type varies as $H^{3/2}$, where H is the head of water on the weir. Thus, a relatively small increase in depth of water causes an appreciable increase in amount. The flow through a submerged-orifice type of control, however, varies as $H^{\frac{1}{2}}$. Increasing the depth of water in front of the orifice from 4 to 9 inches would increase the flow in the ratio of 1.5 to 1, or 50 percent ($9^{\frac{1}{2}} \div 4^{\frac{1}{2}}$). Such an increase in depth over the weir-type control would increase the flow in the ratio of 3.37 to 1, or 237 percent ($9^{3/2} \div 4^{3/2}$).

In furrow-irrigation trials, an overflow structure may be used in the field lateral, with undershot-type controls to divert water from the lateral to the equalizing ditch and to regulate the flow from the equalizing ditch to each furrow (fig. 1). A second overflow-type control may be used in an overflow ditch that leads back to the field lateral, or to additional furrows, to handle surplus water from the equalizing ditch. Such an arrangement is satisfactory for stabilizing furrow streams when the water supply fluctuates.

In border-irrigation trials, a relatively long overflow-type structure is recommended for the field lateral and an undershot type of control to the border strip (fig. 1).
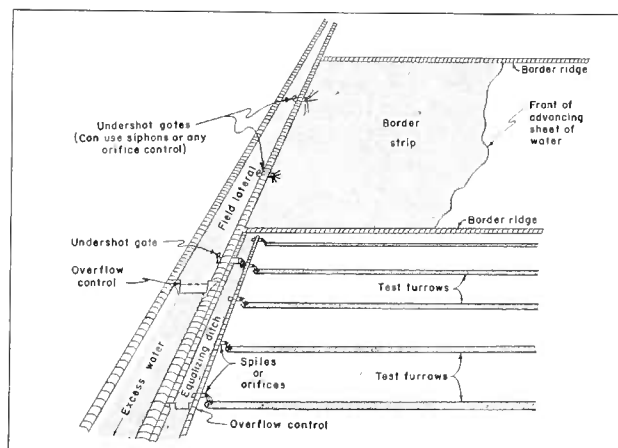

Figure 1.—Suggested layout for conducting irrigation field trials.

Furrow Irrigation

Furrows are used for nearly all row crops that are irrigated by surface methods. Close-growing crops—such as small grains, hay, and pasture—on slopes and on soil that bakes or crusts badly after being wet may also be irrigated with small furrows. These are sometimes called corrugations or rills.

In furrow irrigation, water is delivered to a head ditch or pipeline along the upper edge of the field. It is then diverted into furrows running down or across the slope. Furrows should be long enough to permit economical handling of farm equipment between head ditches but not too long for safe irrigation. Runs should be as long as good soil conservation will allow. This will keep the turning of farm machinery and settings of furrow streams to a minimum.

Since most erosion occurs when land is planted to furrow-irrigated crops, evaluations of furrow-irrigation systems and practices are extremely important, especially where slopes are rather steep. Erodibility of the soil, size of the stream, steepness of the slope, and shape of the furrow are factors involved. Increasing either slope or stream size tends to increase erosion. Decreasing stream size and slope and using wide, shallow furrows tend to decrease erosion.

Increasing the size of stream in a bare, V-type furrow on the steeper grades does not materially increase the rate at which the water enters the soil. A furrow stream of 1 gallon per minute will put about as much water into the soil per foot of furrow as will a stream 10 times as large. This generally is not the case on the gentler slopes, nor where the furrows are broad or grass covered. By using smaller streams, however, the irrigator usually can save both water and soil, with but little more time spent in irrigating if lengths of run are correct.

Equipment Needed for Furrow Test

In general, the equipment for tests of an irrigation system is simple. The items below are needed for furrow-irrigation tests:
1. Engineer's level and rod.
2. Chain or tape.
3. Stakes.
4. Stopwatch and regular watch or clock.
5. Shovel.
6. Spiles, siphons, gated pipe, or some other positive means for controlling discharge of water into furrows.
7. Wide-mouthed gallon jar or can, if the stream is to be measured volumetrically, or some other accurate measuring device such as free-flow or submerged orifices, or small Parshall flumes.
8. Forms for recording evaluation data.

The first five items are available in any irrigation locality. The wide-mouthed jar can be

Figure 2.—Measuring flow in furrow with free-flow orifice plates.

bought at a confectionery store for a few cents, or a can or bucket may be used instead. Spiles may be bought, or built of lath, sheet metal, or lumber. Orifice plates (fig. 2) and small Parshall flumes (fig. 3) are not available commercially but can be built by local sheet-metal shops.

Procedure

The procedure for gathering data to evaluate a furrow-irrigation system is to divert different sized streams into several furrows and check the rate at which the stream fronts advance down them. Each stream is measured at the head of

Figure 3.—Measuring flow through a small Parshall flume.

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Figure 4.—Measuring water volumetrically into a furrow with use of bucket and stopwatch. Gated surface pipe is used in controlling the flow of water to the furrows.

the furrow and at one or more points down field to determine how much water enters the soil.

Before turning water on:
1. Choose several uniform furrows for testing.
2. Set stakes at 50- or 100-foot stations down the field.
3. Run levels on each station to determine average slope and variation in slope.
4. Set spiles, orifice plates, or other controls at heads of the furrows. If the streams are to be measured volumetrically, dig a hole at the lower end of each spile large enough for the container to catch the flow (fig. 4).
5. Select outflow-measuring points down the test furrows and install measuring devices.

Figure 5.—Soil Conservation Service technicians estimating how much additional soil moisture can be stored in the root zone of a potato field.
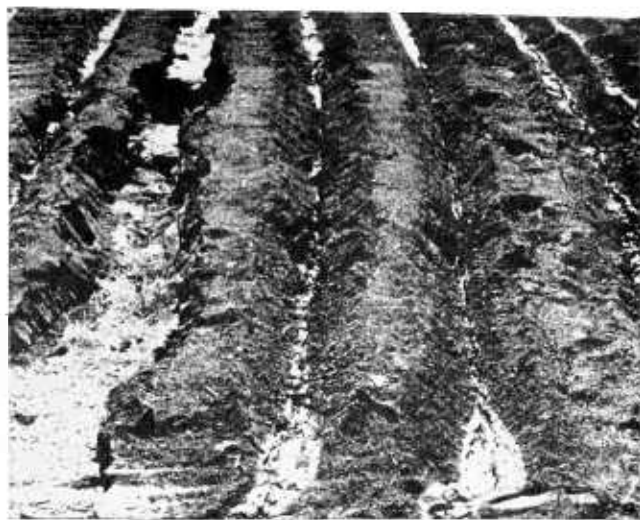
Figure 6.—Erosion being caused by furrow stream too large for slope and soil condition.

6. Estimate how much water can be stored in the crop-root zone (fig. 5). It is assumed that this test will be run at the time the crop is to be irrigated, or, if land is not cropped, when the soil moisture is relatively low.

After turning water on:
1. Set constant-flow streams—a different size for each furrow. Analysis will be easier if the spread in stream sizes is rather large. The largest stream should cause erosion (fig. 6) or be too large for the furrow to carry (fig. 7). The smallest should be too small to advance to the end of the furrow, regardless of how long it is allowed to run. The size of the medium stream may be estimated from the formula $Q=10/S$, where Q is the stream size in gallons per minute and S is the slope of the furrow in percent.

Sometimes, several guard furrows must be set on either side of the test furrows to prevent undue lateral seepage losses.
2. Record the time when water starts to flow into each furrow and when it reaches the stations.
3. Measure streams periodically at the intake to the furrows and record results.
4. Inspect each furrow for erosion or overtopping and estimate the maximum allowable stream. Flowing water nearly always causes some erosion, so cloudiness in the water for the first 5 minutes after a stream passes a point may be permissible. Obvious movement of soil particles and vertical cutting or undercutting along the furrow banks after the initial wetting would be serious erosion. This indicates the need for using a smaller stream.
5. Periodically measure flows in the furrows at the outflow-measuring points. Continue these measurements until flows become practically constant. This may not happen on the fine-textured soils for several hours.
6. After the irrigation, cut a trench across and at right angles to the furrows at several places to disclose the wetting pattern.

Figure 7.—Furrow stream exceeds the carrying capacity of the furrow.

7. Check the adequacy of the irrigation 24 hours or more after the water is turned off. In the fine-textured soils, 2 or 3 days may be required for all the free moisture to be distributed.

8. Determine what adjustments, if any, are needed for safe and efficient irrigation.

Analysis of Results From Irrigation Trial

The most important factors are: (a) water needed to refill the soil-moisture reservoir, (b) intake rates, (c) time required to refill the soil-moisture reservoir, (d) maximum furrow spacing, (e) maximum allowable time to get water through the furrows, (f) maximum allowable furrow stream, and (g) maximum allowable length of run.

Water needed to refill soil-moisture reservoir

Before irrigating, subtract the amount of moisture in the root zone from the field capacity to find the amount of water needed to refill the soil-moisture reservoir (fig. 8). Laboratory determinations of soil-moisture conditions just before and after irrigation are desirable, of course. But if they cannot be made readily, the soil-moisture conditions can be judged with a reasonable degree of accuracy by the "feel" method (table 1).

Intake rates of the soil

The rate at which the soil absorbs water usually decreases rather rapidly for a time after the start of an irrigation. After several hours, however, it usually becomes nearly constant. When the intake rate during a normal irrigation is plotted on log paper on the vertical axis and time on the horizontal axis, the resultant curve has a general shape indicated by the formula $I = KT^n$ Where:

I = Intake rate of the soil.

T = Time that water is on the surface of the soil.

K = Intake-rate intercept at unit time.

n = Slope of the line (vertical scaled distance divided by horizontal scaled distance).

In furrow irrigation, only part of the land surface is in contact with the water, so the equivalent field-intake rate [1a] will vary with both the rate

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[1a] Field intake rate is defined as the rate at which water is absorbed in acre-inches per acre per hour.

TABLE 1.—*Guide for judging how much moisture is available for crops*

Soil moisture remaining	Feel or appearance of soil			
	Very light texture	Light texture	Medium texture	Heavy and very heavy texture
0 percent	Dry, loose single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked; sometimes has loose crumbs on surface.
50 percent or less	Appears to be dry, will not form a ball with pressure.[1]	Appears to be dry, will not form a ball.[1]	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.[1]
50 to 75 percent	Same as very light texture with 50 percent or less moisture.	Tends to ball under pressure but seldom holds together.	Forms a ball, somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent).	Tends to slick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily if relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent).	Upon squeezing no free water appears on soil but wet outline of ball is left on hand.	Same as very light texture.	Same as very light texture.	Same as very light texture.

[1] Ball is formed by squeezing a handful of soil very firmly.

1	2	3	4	5	6	7	8	9	10
Depth (feet)	Soil texture					Available moisture capacity	Soil moisture before irrigation		Moisture deficiency
	Very heavy	Heavy	Medium	Light	Very light				
						Inches	Percent	Inches	Inches
0-1			X			2.00	20	0.40	1.60
1-2			X			2.00	40	0.80	1.20
2-3				X		1.25	50	0.62	0.63
3-4				X		1.25	50	0.62	0.63
4-5									
5-6									
Total						6.50		2.44	4.06

Available moisture capacity in inches of water per foot depth of soil under average conditions: very heavy, 2.00; heavy, 2.20; medium, 2.00; light, 1.25; very light, 0.75.

Figure 8.—Form for figuring the amount of water needed to refill the soil to its moisture-holding capacity.

at which water is absorbed from the furrow and the furrow spacing. Since the amount of water entering and leaving a furrow or a section of it is usually measured in gallons per minute, the furrow-intake rate is commonly computed in gallons per minute per 100 feet of furrow. Dividing the intake rate in gallons per minute per 100 feet of furrow by the furrow spacing in feet gives the approximate field-intake rate in inches per hour. Figure 9 may be used in making this computation.

Time required to refill the soil-moisture reservoir

The area under the curve—from the formula $I=KT^n$—divided by 60 is equal to the depth of water (D) absorbed by the soil when the curve is plotted from the formula $I=KT^n$ with time (T) expressed in minutes and intake rate (I) in inches per hour. The area under the curve as determined by integration is:

$$60D=\frac{K}{n+1}\ T^{n+1} \text{ and } T=\left[\frac{60D\,(n+1)}{K}\right]^{\frac{1}{n+1}}$$

Maximum furrow spacing

Furrow spacing in row crops is usually fitted to the type of crop or equipment. Spacing can be varied in some crops, as, for example, in orchards or close-growing crops irrigated with corrugations.

In medium-textured soils that are homogeneous throughout the root zone of the crop, the depth and width of the wetted bulb of soil beneath the furrow are frequently about the same. Maximum furrow spacing in such soils should not exceed the depth of root zone of the mature crop. When the plants are small, with undeveloped root systems, much of the irrigation water may percolate down below their reach if enough is applied to get adequate lateral penetration with the maximum furrow spacing. Higher application efficiencies should be possible when plants are more nearly mature.

Generally, the soil profile is not homogeneous.

A layer of slowly permeable soil within or near the root zone may cause a temporary perched water table and wide horizontal movement of the water. In contrast, an extremely permeable underlayer may curtail horizontal movement. Therefore, the soil profile and pattern made by the percolating waters should be known before furrow spacing is recommended.

Maximum allowable time for getting water through the furrows

If the intake rate is uniform throughout the length of the furrow, absorption of water by the soil will be uniform along each segment for equal periods of time. Water, however, normally advances much more slowly down a furrow when it is dry than it flows from the furrow after it is wet and the water is turned off. Ordinarily, the water is in the upper end of the furrow longer than at points farther down.

For nearly uniform irrigation of a field, the stream fronts should reach the lower ends of the furrows within one-fourth of the total time needed to refill the soil in the root zone. Thus, the "opportunity time" for the soil to absorb water will be about 25 percent greater at the upper than at the lower end of the field. But the water-intake rate of the soil decreases with time, frequently inversely proportional to the square root of the elapsed time. So, the amount of water absorbed during this extra time will be less than 25 percent of the total. If the square-root relationship is correct, about 12 percent more will be absorbed at the upper than at the lower end. The average deep-percolation loss for the full length of the furrow would, therefore, be in the magnitude of 5 percent (fig. 10).

Maximum allowable furrow stream

Hardest to determine, because of the lack of accurate information, is the maximum allowable
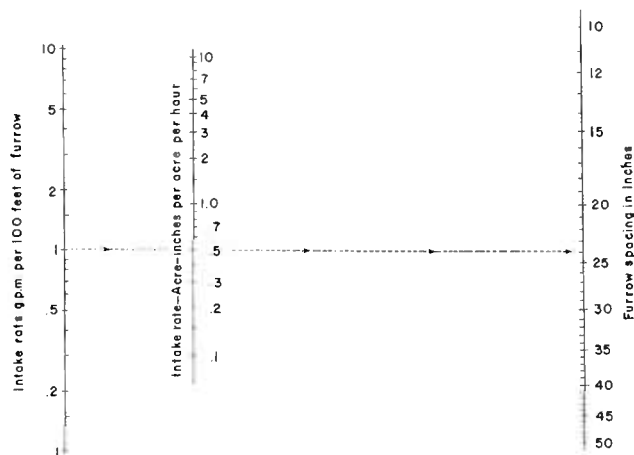
Figure 9.—Nomograph for converting intake rate in gallons per minute per 100 feet of furrow to acre-inches per acre per hour for various furrow spacings.
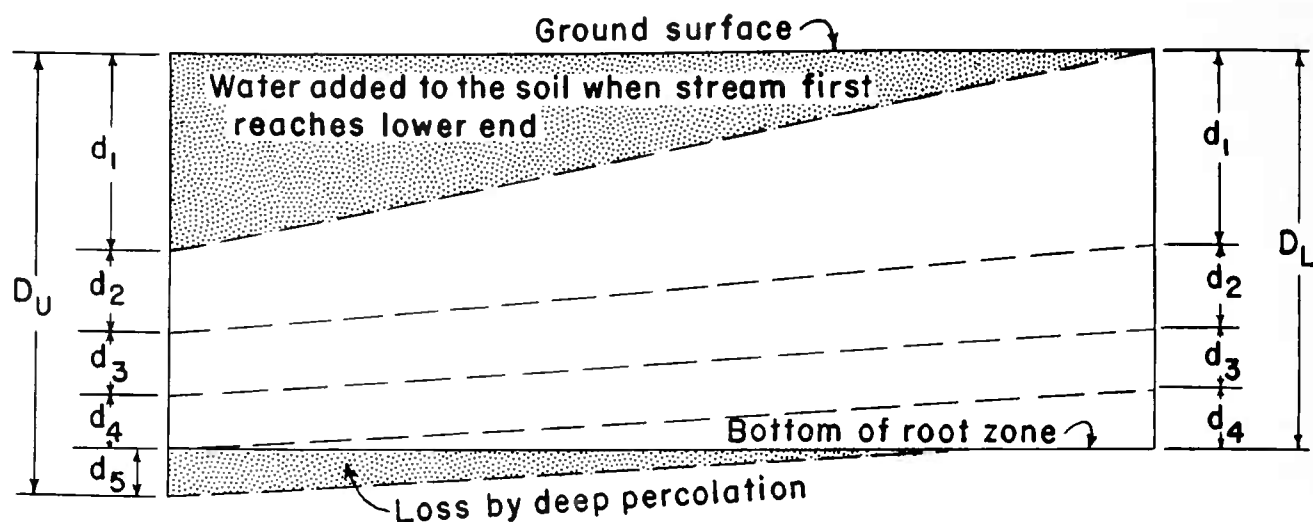
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Figure 10.—Profile along furrows showing water penetration when intake rate is inversely proportional to square root of elapsed time.

Assume

T = Time required to refill root zone

$T/4$ = Time required for furrow stream to reach lower end of furrow

$d_1, d_2, d_3, d_4,$ and d_5 = Depths of water absorbed in equal time increments $T/4$

With intake varying inversely with the square root of time

$d_2 = (\sqrt{2}-1)d_1, d_3 = (\sqrt{3}-\sqrt{2})d_1, d_4 = (2-\sqrt{3})d_1,$ and $d_5 = (\sqrt{5}-2)d_1$

$D_L = d_1(1+\sqrt{2}-1+\sqrt{3}-\sqrt{2}+2-\sqrt{3}) = 2d_1$—Absorbed at lower end

$D_U = d_1(1+\sqrt{2}-1+\sqrt{3}-\sqrt{2}+2-\sqrt{3}+\sqrt{5}-2) = \sqrt{5}d_1$—Absorbed at upper end

Then

Average deep percolation = $(\sqrt{5}-2)\dfrac{d_1}{2}$

Average depth absorbed = $\dfrac{2d_1+\sqrt{5}d_1}{2} = (2+\sqrt{5})\dfrac{d_1}{2}$

To find the percentage of water absorbed that will be lost to deep percolation:

$$\frac{100(\sqrt{5}-2)\dfrac{d_1}{2}}{(2+\sqrt{5})\dfrac{d_1}{2}} = \frac{100(\sqrt{5}-2)}{(2+\sqrt{5})} = \frac{23.6}{4.236} = 5.3 \text{ percent}$$

furrow stream. This is largely a matter of judgment, and any two people working independently may arrive at somewhat different conclusions. Until a quick, reliable method is devised to measure the erosion caused by streams of different sizes, and the amount of erosion permissible on the various soils is determined, decision on the maximum allowable stream will have to rest on judgment.

Unfortunately, surface irrigation cannot be practiced without some movement of soil material. There may be damaging erosion at the top of a sloping irrigated field, where the stream is largest, but practically no soil movement at the bottom. Removal of soil from the top and deposition farther down may be as serious as if soil were removed from the field. Site conditions affect the seriousness of soil erosion. Certainly, removal of an inch from a field having many feet of good soil is less a threat to permanent agriculture than removal of an inch of soil from a field underlain at 15 inches by rock. Accordingly, serious erosion needs to be defined locally.

Erosion may be no problem on nearly flat grades. The limit on the size of furrow stream may be the carrying capacity of the furrow.

Because the intake rate decreases with time and some ponding occurs in the furrow, it usually is well to "cut back" the furrow stream after it has reached or approached the end of the furrow. Unless this is done, loss of water by surface waste is likely to be heavy. A cutback may not be necessary where grades are nearly flat and furrows have adequate storage capacity.

The maximum stream, as previously determined, need not always be used for good irrigation. A smaller stream will be satisfactory if it will reach the lower end of a field within the "one-fourth time" criterion.

Maximum allowable length of run

The maximum allowable length of run is the longest distance in which the maximum allowable furrow stream can effect nearly uniform distribution of water in the soil. This can be decided after plotting the rate at which the different size streams advance and determining the maximum size stream and maximum time that can be allowed for it to get down the furrow. Somewhat higher efficiencies might be obtained if the fields are shorter than the maximum allowable.

Station	Elevation	Furrow No. 1 Clock time (24-hr.)	Elapsed time	Furrow No. 2 Clock time (24-hr.)	Elapsed time	Furrow No. 3 Clock time (24-hr.)	Elapsed time	Furrow No. 4 Clock time (24-hr.)	Elapsed time
	Feet		Minutes		Minutes		Minutes		Minutes
0 +00	100.0	8:00	start	8:02	start	8:05	start	8:10	start
1 +00	98.2	9:30	90	8:24	22	8:18	13	8:20	10
2 +00	96.1	13:33	333	9:31	89	8:47	42	8:37	27
3 +00	93.9			11:17	195	9:35	90	9:07	57
4 +00	92.0			15:25	443	10:43	158	9:42	92
5 +00	90.1			16:35	513	12:04	239	10:33	143
6 +00	88.4					13:38	333	11:32	202
7 +00	86.1					15:42	457	12:36	266
8 +00	83.9							13:47	337
1 +50		11:07	187						
2 +40		16:20	500						

Estimated maximum allowable furrow stream 5.0 g.p.m.
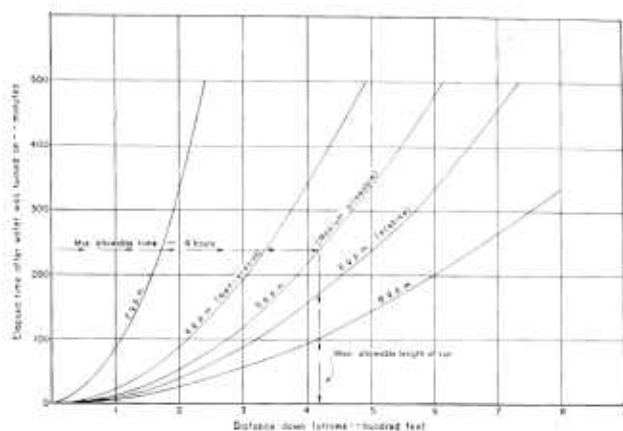
Figure 11.—Rate-of-advance data.

Figure 13.—Rate-of-advance curve for determining maximum length of furrows.

the direction of irrigation is 2 percent.

Furrow stream rate-of-advance and flow measurements are recorded on figures 11 and 12, and plotted on figure 13.

Water-storage capacity

The soil was examined by 1-foot increments to a 4-foot depth just before the irrigation trial, and it was found to be of uniform texture throughout. Its capacity for holding usable water was estimated at about 2.0 inches per foot of depth, or 8.0 inches in the root zone. The depth of water needed to refill the root zone was estimated to be 3.75 inches.

Water-intake rate of the soil

The water-intake rate of the soil was determined by measuring the flow into and out from the furrow. When the average intake-opportunity time was 14 minutes, water was being absorbed at the rate of 3.40 g. p. m. per 100 feet of furrow. With the furrow spacing 42 inches, this is equivalent to a field-intake rate of 0.94 inch per hour. After 478 minutes, the intake rate was 0.60 g. p. m. per 100 feet of furrow, or a field rate of 0.17 inch per hour. Table 2 gives complete results; values are plotted on figure 14. The variation of field-intake rate with time is given by the formula $I=3.58\ T^{-0.5}$.

Time required to refill the soil-moisture reservoir

Since the formula for the intake-rate curve is known, the time required to put the 3.75 inches into the soil can be computed with the formula:

$$T=\left[\frac{60D(n+1)}{K}\right]^{\frac{1}{n+1}}$$

From figure 14 K is seen to be 3.58 and $n=-0.5$. Thus

Furrow No. 1 Inflow station 0+00 Clock time	Sec./gal.	Flow g.p.m.	Outflow station Clock time	Sec./gal.	Flow g.p.m.	Furrow No. 2 Inflow station 0+00 Clock time	Sec./gal.	Flow g.p.m.	Outflow station 1+00 Clock time	Sec./gal.	Flow g.p.m.
8:00	30	2.0				8:02	15	4.0	8:27	100.0	0.60
									8:50	31.6	1.90
8:30	29.8	2.0				8:35	14.9	4.0	9:20	24.6	2.44
									10:00	21.4	2.80
9:05	30.0	2.0				9:07	15.0	4.0	11:10	20.0	3.00
									12:30	19.2	3.12
10:30	30.1	2.0				10 35	15.2	3.9	14:00	18.2	3.30
									16:00	17.7	3.40
12:00	30.0	2.0				12:03	15.0	4.0			
13:30	30.0	2.0				13:31	15.0	4.0			
16:30	30.0	2.0				16:35	15.0	4.0			

Furrow No. 3 Inflow station 0+00 Clock time	Sec./gal.	Flow g.p.m.	Outflow station Clock time	Sec./gal.	Flow g.p.m.	Furrow No. 4 Inflow station 0+00 Clock time	Sec./gal.	Flow g.p.m.	Outflow station 6+00 Clock time	Sec./gal.	Flow g.p.m.
8:05	10	6.0				8:10	7.5	8.0	11:40	300.0	0.20
									12:00	42.9	1.40
8:40	9.8	6.1				8:45	7.5	8.0	12 40	26.1	2.30
									14:10	18.8	3.20
9:10	10.0	6.0				9:15	7.5	8.0	16:15	14.4	4.16
10:38	10.0	6.0				10:40	7.5	8.0			
12:05	10.1	5.9				12:07	7.5	8.0			
13:33	10.0	6.0				13:35	7.5	8.0			
16:38	10.0	6.0				16:40	7.5	8.0			

Figure 12.—Furrow-stream measurements.

But, if the fields are only slightly longer than the maximum allowable, a lower irrigation efficiency might be preferable to cutting the run in two.

Sample Analysis

The information needed and methods of analysis can best be illustrated by a sample evaluation of a cornfield. Rows are 42 inches apart. The soil is medium-textured and uniform throughout the root-zone depth of 48 inches. The slope in

$$T = \left[\frac{(60 \times 3.75)\,(-0.5+1.0)}{3.58}\right]^{\frac{1}{-0.5+1}}$$

$$= \left[\frac{225 \times 0.5}{3.58}\right]^2 = 987 \text{ minutes}$$

$$= 16.5 \text{ hours}$$

Maximum furrow spacing

Since a row crop is on the sample field, furrow spacing is fixed. With the deep, medium-textured soil found here, however, the 42-inch furrow spacing should give reasonably good lateral wetting by the time the proper amount of water is put into the soil. Excavation across the furrow indicated this to be the case.

Maximum allowable time to get water through the furrow

Since 16 hours would be required for the soil to absorb the necessary 3.75 inches of water, the furrow stream has to reach the lower end of the field in 4 hours to meet the criterion for good irrigation. Thus, the water would need to be on the upper end of the field 20 hours—4 hours for the furrow streams to reach the lower end plus 16 hours needed to store 3.75 inches of water at the lower end.

TABLE 2.—*Measurement of furrow-intake rate*

FURROW NO. 2

Clock time (24-hr.)	Elapsed time—			Inflow	Out-flow	Loss in furrow	Intake per 100 ft.
	Station 0+00	Station 1+00 [1]	Aver-age				
	Min-utes	Min-utes	Min-utes	G.p.m.	G.p.m.	G.p.m.	G.p.m.
8:02	Start	------	------	4.0	------	------	------
8:24	22	0	------		------	------	------
8:27	25	3	14		0.60	3.40	3.40
8:50	48	26	37		1.90	2.10	2.10
9:20	78	56	67	Con-stant Flow	2.44	1.56	1.56
10:00	118	96	107		2.80	1.20	1.20
11:10	118	166	177		3.00	1.00	1.00
12:30	268	246	257		3.12	.88	.88
14:00	358	336	347		3.30	.70	.70
16:00	478	456	467	4.0	3.40	.60	.60

FURROW NO. 4

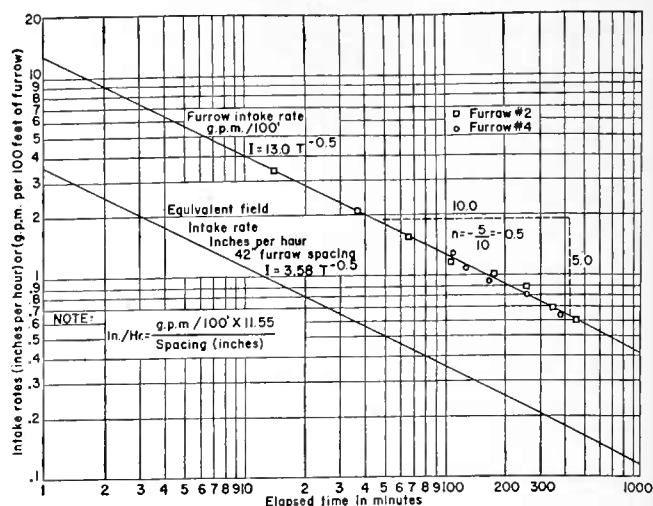|							
8:10	Start	------	------	8.0	------	------	------
11:32	202	0	------		------	------	------
11:40	210	8	109	Con-stant Flow	0.20	7.80	1.30
12:00	230	28	129		1.40	6.60	1.10
12:40	270	68	169		2.30	5.70	.95
14:10	360	158	259		3.20	4.80	.80
16:15	485	283	384	8.0	4.16	3.84	.64

[1] For furrow No. 4 station 6+00.

Figure 14.—Intake-rate curves for furrow irrigation.

Maximum allowable furrow stream

Furrow streams of 2, 4, 6, and 8 g. p. m. were tried. The largest eroded more soil than could be allowed. The 6-g. p. m. stream washed some loose soil during the initial wetting and continued to move a little soil as the stream was running. This was evidenced by some cloudiness of the water and a small amount of undercutting of the furrow bank. The 4-g. p. m. stream caused little soil movement, even with the initial flush. It was decided that 5 g. p. m. were the safe maximum furrow flow for these conditions.

Because of the decrease in the intake rate with time and ponding in the furrow, the stream should be "cut back" after it has reached or approached the end of the furrow. In the example, the furrow stream could be reduced to about 3.5 g. p. m. shortly after it reached the lower end of the furrow, with further cuts from time to time as desired.

Maximum allowable length of run

Figure 13 shows the maximum allowable length of run. The length of run is indicated by the point where the line for the maximum allowable time to get the water through the furrows intersects the plotted curve of the maximum allowable furrow stream. In this case it is 420 feet.

Conclusions

On this sample field, the 800-foot-long furrows cannot be irrigated safely without excessive deep-percolation and/or soil losses. The maximum nonerosive furrow stream is 5 g. p. m., which will advance only 420 feet in ¼ the time needed to refill the soil-moisture reservoir. An intermediate head ditch should be built so the field can be irrigated in two 400-foot runs. Also, if 5-g. p. m. streams are used to get the water through the furrows, they should be "cut back" to about 3.5 g. p. m. shortly after they reach the lower ends to prevent excessive losses from surface runoff.

Border Irrigation

Border irrigation can be used for all close-growing crops, some row crops, and orchards where topography and soils are suitable. It permits efficient, rapid, and relatively easy irrigation if the borders are properly constructed. Labor requirements are low. Relatively large streams of water are required. The layouts must have nearly flat, uniform grades and good land preparation. Border strips must be level transversely.

Although border irrigation is suitable for most soil types, it may not be desirable on fine-textured soils where surface baking occurs unless moisture to get the crops established can be applied some other way. Sprinklers or corrugations between the border ridges are sometimes used. Often, natural precipitation will suffice to start the crop.

This section describes a technique to gather information for evaluating an existing border-irrigation system and determining the proper size streams of water.

Equipment Needed for Test

Equipment needed to conduct field tests on border-irrigation systems includes:
1. Engineer's level and rod.
2. Chain or tape.
3. Stakes, ax, and crayon.
4. Regular watch or clock.
5. Shovel and soil auger.
6. Weirs, submerged orifices, Parshall flumes, calibrated siphons, or other devices for measuring water to and from border strips.
7. Forms for recording data.

Procedure

The first step in evaluating border irrigation is to determine the "basic intake rate"[2] and water-holding capacity of the soil in the root zone. Then release a stream of predetermined size into a border strip, and time both its advance down the strip and how long the water covers each part. Compute the depth of water applied and determine the uniformity with which it is absorbed. Repeat this process one or more times if the stream is found to be not of proper size.

Before releasing water into border strips:[3]
1. Choose a border strip into which a constant-size stream can be directed, and which will permit

[2] In this handbook, the "basic intake rate" is the rate at which water will enter the soil after a period of several hours, when the change in rate becomes very slow.

[3] It is assumed that the trial run will be made at the time the crop is in need of irrigation. If the test is run when the soil is wet, the intake rate of the soil may be much slower and the rate of advance of the water much faster than when the soil is in need of irrigation.

measurement of the waste water if runoff occurs.[4]
2. Measure the width of the border strip.
3. Set stakes at 50- or 100-foot stations down the border.
4. Run levels on each station to determine the average slope and variation in slope.
5. Set weirs or other measuring devices at the upper end of the border strip, and at the lower end if surface runoff is expected.
6. Determine, by excavation if necessary, the depth of the root zone of the crop on the field.
7. Estimate the amount of water needed to fill the root zone.
8. Measure or estimate the basic intake rate of the soil. One method frequently used is to drive a cylinder about 15 inches long and 9 to 12 inches in diameter into the soil to a depth of 4 to 6 inches, add water, and determine the rate at which it is absorbed during various periods.
9. Determine from figures 12 and 13 the approximate size of stream to use.

Turn water on: Make sure that the stream size does not fluctuate. Do not use a stream large enough to cause erosion or overtop the border ridges. If the strip is wide, more than one opening from the head ditch to the border strip may be required to avoid erosion near the turnout.

After turning water on:
1. Record the time water starts to flow into the border strip and the time the front of the sheet of water reaches each station. If the front is an irregular line across the border strip, use the average of the times that the different parts reach each station.
2. Record the time when the waste stream, if there is any, starts, and measure the flow periodically until it ceases.
3. Record the time when water is turned off at the head of the field and the time when the sheet of water recedes past each station. This requires good judgment. On slopes above 0.5 percent, a large part of the water in the border strip when the supply is shut off may move down slope in a fairly uniform manner. On these fields, record recession time at each station when the water has disappeared from the area above it. If the recession line across the border strip is irregular, record the time when there is about as much cleared area below as there is water-covered area above the station. On slopes below 0.5 percent, a smaller proportion of the water moves down the strip. Some may be trapped in small depressions and may not be absorbed for some time after surrounding areas are clear. Since the important thing is to determine when the intake opportunity

[4] On soils having a fairly rapid intake rate, border strips laid out on a flat slope may have little, if any, surface runoff. On the other hand, fairly uniform distribution of the water down the border on steeper slopes with tight soil may be impractical without some surface waste.

TABLE 3.—*Suggested maximum safe irrigation streams in cubic feet per second per foot of border strip width* [1]

Slope (S)	Maximum stream (Q) [2]	Slope (S)	Maximum stream (Q) [2]
Percent	*Cubic feet per second*	*Percent*	*Cubic feet per second*
0.3	0.150	1.0	0.060
.4	.120	1.5	.043
.5	.100	2.0	.035
.6	.086	2.5	.030
.7	.077	3.0	.026
.8	.070	4.0	.021
.9	.064	5.0	.018

[1] For border strips without sod protection. Larger streams may be used with sod cover.
[2] $Q = 0.06S^{-0.75}$.

Figure 16.—**Factors for use in adjusting unit streams from figure 15 for slopes other than 0.5 percent.**

is essentially gone, the recession time usually may be recorded for a station when 80 to 90 percent of the area between it and the next station upstream has no water on the surface.

4. Check the adequacy of the irrigation at a number of places with an auger or soil tube 24 hours or more after the water is turned off. Two or more days may be required for the free moisture to be distributed in the fine-textured soils.

5. Plot the "rate of advance" and the "recession curves" of the sheet of water.

6. Determine the average depth of water absorbed by the soil and uniformity of distribution.

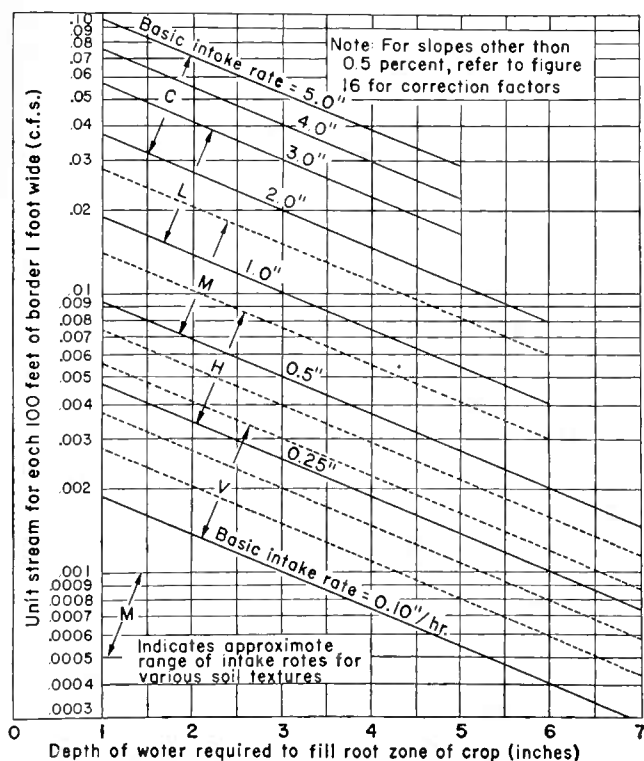7. If analysis of data indicates that some ad-

justments are desirable, make them, and repeat the entire process.

As with furrow irrigation, determining the maximum allowable stream is largely a matter of judgment. Erosion may be significant, however, on slopes of 0.3 percent or more which have poor vegetative protection, if streams larger than those indicated in table 3 are used.

Where a dense sod has been established on stable soils, border streams up to twice the size indicated in table 3 have been used safely.

On slopes less than 0.3 percent, the maximum stream usually will be governed by the height of border ridges. On such slopes, with cover crops, streams of 0.15 c. f. s. per foot of border strip width may be expected to have flow depths of 6 to 8 inches. Streams of 0.2 c. f. s. per foot of border-strip width may be more than 8 inches deep. Border ridges with settled heights more than 8 inches are usually difficult to build and maintain, so the use of streams larger than about 0.12 to 0.15 c. f. s. per foot of border-strip are generally inadvisable.

The intake rate of the soil, slope, width and length of the border strip, depth of application, height of the border ridges, and erosion are all considered in determining the size of border stream to use. Figures 15 and 16 show relationships of these factors, based on empirical data from many sites.

Stream sizes are shown as "unit streams" (the stream required for each 100 feet of border strip 1 foot wide). Sizes of border streams can be determined by multiplying the unit stream by the product of the border-strip width in feet times the length in hundreds of feet (border-strip area in hundreds of square feet). The unit streams shown in figure 15 are for a 0.5-percent slope. For other slopes, multiply these unit streams by the slope factors in figure 16.

Intake rates used in figure 15 are basic rates. They are not the average rates for the irrigation period, nor are they necessarily the rate at the time an irrigation is completed. Often the required amount of water may enter the soil before the basic intake rate is reached.

It must be remembered, however, that although texture may give an indication of the intake rate, other factors may cause the actual rate to differ greatly from one estimated on the basis of texture alone. The design of any border-irrigation sys-

Figure 15.—**Curves for estimating unit-border streams on slopes of 0.5 percent.**

tem should be based only on measured intake rates under existing field conditions.

Sample Analysis

The easiest way to explain the evaluation process and the reasons for gathering the information is to describe a complete field trial and analyze the results. A loam soil with a basic intake rate of 1.0 inch per hour, and irrigated as the farmer was accustomed to doing, is used. The border strip has a 0.5-percent slope, is 20 feet wide and 1,000 feet long. The crop is wheat. Four inches of water need to be put into the root zone, which is about 4 feet deep.

Determining basic intake rate

Rings (fig. 17) were used as described on page 11 to measure the water-intake rate. Table 4 shows the data. The variation of intake rate with time is plotted in figures 18 and 19. Studies to date indicate that the intake rate as measured by rings usually is comparable to the actual intake rate under border irrigation.

The intake-rate curves show that the final, or basic, rate is about 1.0 inch per hour, but the accumulated intake curves show that the first 4 inches of water would percolate into the dry soil in 40 minutes. Therefore, deep percolation will occur if water is held on the land longer than about

Figure 17.—Intake rings in operation. The rate at which water enters the soil at various times and the time required to store a given amount of water in the soil are observed. The final (basic) intake rate and the depth of water to be applied are used as a basis for determining the size of the border-irrigation stream needed.

40 minutes. Some deep percolation may occur if the soil in the root zone is to be fully wetted throughout the length of run but it can be held to a minimum by properly balancing the size of stream, area of border strip, and time of application.

TABLE 4.—*Ring-intake data*

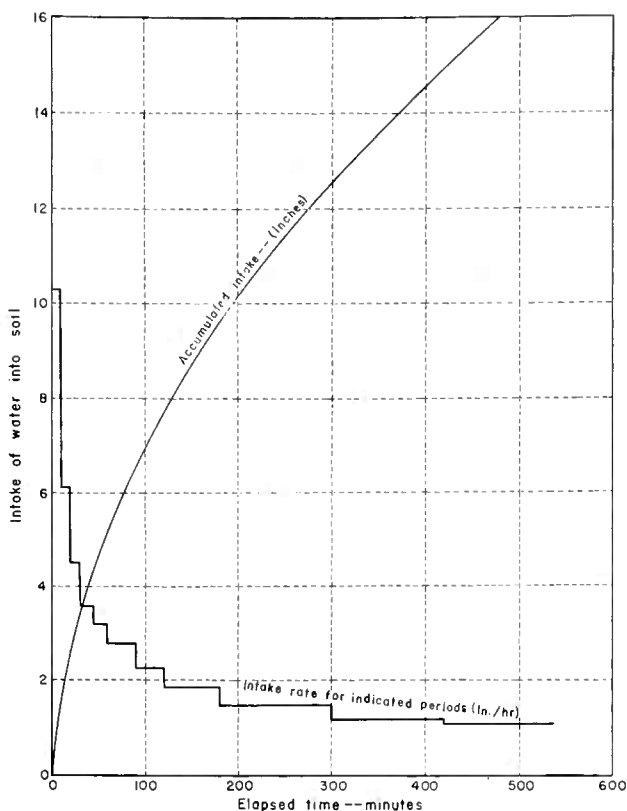| Observed time 24-hr. clock	Elapsed time—		Distance to water surface from reference point		Intake during period		Accumulated intake during test	
	Since last reading	Since beginning of test	Before filling	After filling	Depth	Average rate per hour	Depth	Average rate per hour
	Minutes	*Minutes*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
8:00			Fill	0.0				
					1.72	10.3		
8:10	10	10	1.72				1.72	10.3
					1.02	6.1		
8:20	10	20	2.74				2.74	8.2
					.75	4.5		
8:30	10	30	3.49				3.49	7.0
					.90	3.6		
8:45	15	45	4.39	.0			4.39	5.9
					.80	3.2		
9:00	15	60	.80				5.19	5.2
					1.40	2.8		
9:30	30	90	2.20				6.59	4.4
					1.15	2.3		
10:00	30	120	3.35	.0			7.74	3.9
					1.90	1.9		
11:00	60	180	1.90				9.64	3.2
					3.00	1.5		
13:00	120	300	4.90	.0			12.64	2.5
					2.40	1.2		
15:00	120	420	2.40				15.04	2.2
					2.20	1.1		
17:00	120	540	4.60				17.24	1.9

Figure 18.—Ring-intake curve.

Figure 19.—Ring-intake curves.

Rate of advance of water

The water's rate of advance down the border strip is extremely important. The water was run onto the land for 230 minutes in the first trial (table 5 and fig. 20), but it took 300 minutes for it to reach the lower end of the field. Percolation into the soil was not uniform. Much more water was received by the upper than the lower end of the border strip.

Recession of sheet of water

How long the water stands on a border strip after the stream is turned off usually is significant. See table 5 and figure 20 for the recession data. Note that the water was turned off 70 minutes before the front of the water sheet reached the end of the border strip.

Analysis of data

Inasmuch as only 40 minutes were needed to fill the root zone to field capacity, much water was lost by deep percolation in the 1,000-foot run. The shaded area above the "advance curve" in figure 20 represents the time water must be on the field at any point to refill the root zone. The area between the shaded area and the "recession curve"

shows the time during which deep percolation takes place.

An average depth of 8.3 inches of water (fig. 21) was applied to the field during the 230 minutes, giving an irrigation efficiency of $4.0/8.3 \times 100$, or only 48 percent. There was no surface runoff, so 52 percent was lost as deep percolation.
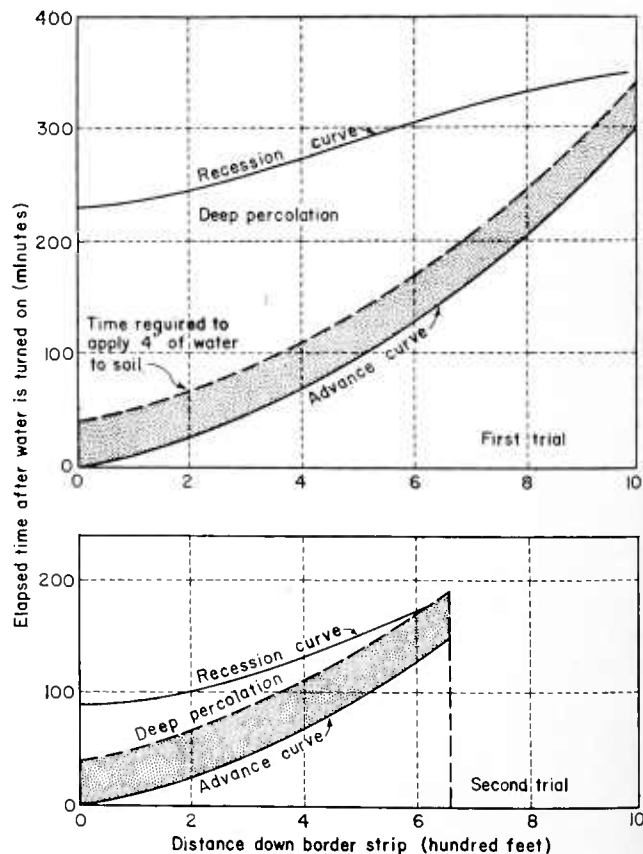
The unit stream (Q_u), used by the farmer on

Figure 20.—Advance and recession curves from border-irrigation field trial.

TABLE 5.—*Data from border-irrigation field trial*

FIRST TRIAL

Station	Elevation	Time water is on the land				Measurement of water retained			
		Advance of water sheet		Recession of water sheet		Inflow station 0+00		Outflow station	
		Clock time (24-hr.)	Elapsed time [1]	Clock time (24-hr.)	Elapsed time [1]	Clock time (24-hr.)	C. f. s.	Time	C. f. s. or g. p. m.
	Feet		*Minutes*		*Minutes*				No outflow
0		8:00	0	11:50	230	8:00	On		
1		8:12	12	11:56	236	8:05	1.00		
2		8:27	27	12:07	247	9:00	1.00		
3		8:47	47	12:18	258	11:30	1.00		
4		9:10	70	12:33	273	11:50	Off		
5		9:36	96	12:49	289				
6		10:10	130	13:07	307				
7		10:45	165	13:20	320				
8		11:28	208	13:32	332				
9		12:14	254	13:42	342				
10		13:00	300	13:48	348				

SECOND TRIAL

Station	Elevation	Clock time (24-hr.)	Elapsed time [1]	Clock time (24-hr.)	Elapsed time [1]	Clock time (24-hr.)	C. f. s.	Time	C. f. s. or g. p. m.
0		14:00	0	15:30	90	14:00	On		No outflow
1		14:12	12	15:32	92	14:10	1.00		
2		14:27	27	15:41	101	14:30	1.00		
3		14:47	47	15:57	117	15:00	1.00		
4		15:10	70	16:12	132	15:30	Off		
5		15:36	96	16:31	151				
6		16:10	130	16:50	170				
6+60		16:30	150	17:10	190				

[1] After water is turned on at head of field.

this field, was the total stream (Q) divided by the width of the strip (W) in feet and the length of the field (L) in hundreds of feet or:

$$Q_u = \frac{Q}{WL} = \frac{1.0}{20 \times 10} = 0.005 \text{ c. f. s.}$$

Faults of this irrigation system could be corrected in either of two ways. First, the stream could be increased so that it would reach the lower end of the field more quickly than before. It then would be turned off sooner. Secondly, the border strip could be shortened. Additional water was not available, so it was decided to shorten the length of run.

The unit stream needed to replace 4 inches of water in the root zone in a soil with an intake rate of 1.0 inch per hour is given in figure 15 as 0.0075 c. f. s.; or, for a 20-foot strip, 0.15 c. f. s. for each 100-foot length. If 1.0 cubic foot per second is the maximum stream available, the maximum length of run should be about 1.0/0.15×100 or 660 feet.

Data from the second trial, using the shorter length of run, are also given in table 5 and plotted in figure 20. They indicate fairly efficient application, with the water well distributed throughout the border strip.

Figure 21 shows that the use of a unit stream of 0.0075 c. f. s. for 90 minutes gives a total application of about 5 inches. With only 4 inches being stored in the root zone, the application efficiency was 4.0/5.0×100 or 80 percent.

Problems Encountered in Border Irrigation

These figures on stream-area relationships are for use only as a guide, but they may be used to obtain tentative answers to some problems in border irrigation. Following are three examples of the use of this information:

A. *Known:*
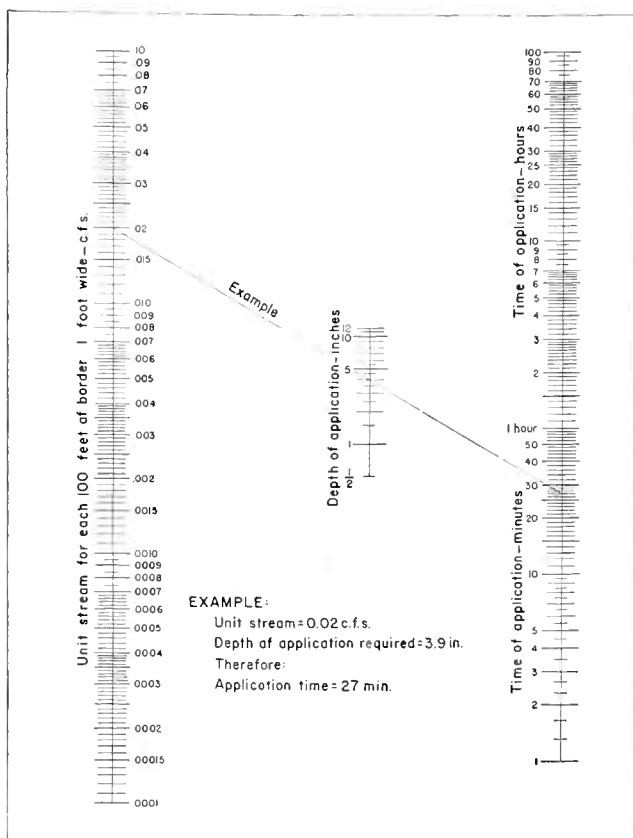 1. Length of field: 1,320 feet.
  2. Basic intake rate: 0.25 in./hr.

Figure 21.—Chart for determining time required to apply various depths of water with different size of unit streams.

EXAMPLE:
Unit stream = 0.02 c.f.s.
Depth of application required = 3.9 in.
Therefore:
Application time = 27 min.

3. Slope: 0.5 percent.
4. Root zone of crop will hold 5 inches of water.
5. Desired border-strip width: 40 feet.

Desired:
1. Size of stream to be used.
2. Length of time required to irrigate each strip.

Answer:
1. The unit stream (fig. 15) is 0.00133 c. f. s. Therefore, the stream for the strip is $0.0013 \times 13.2 \times 40 = 0.68$ c. f. s.
2. A unit stream of 0.00133 c. f. s. will apply 5 inches depth of water in about 8.3 hours (fig. 21). Assuming an application efficiency of 70 percent, the total time is 8.3/0.70, or about 12 hours.

B. *Known:*
1. Size of available stream is 1.0 c. f. s.
2. Desired width of border strip: 24 feet.
3. Basic intake rate: 1.5 in./hr.
4. Slope: 0.5 percent.
5. Root zone of crop will hold 4 inches of water.

Desired:
1. Length of border strip recommended.
2. Time required to apply water.

Answer:
1. The recommended unit stream is 0.011 c. f. s. (fig. 15). Therefore, the length of border =

$$\frac{1 \text{ c. f. s.}}{24 \times 0.011} \times 100 = 378 \text{ ft.}$$

2. A unit stream of 0.011 c. f. s. will apply 4 inches depth of water in 48 minutes (fig. 21). Assuming an application efficiency of 70 percent, the stream would have to be on the field for about 70 minutes.

C. *Known:*
1. Length of field: 440 feet.
2. Basic intake rate: 2.5 inches per hour.
3. Slope: 1 percent.
4. Width of border desired: 20 feet.
5. Depth of application required: 2.0 inches.

Desired:
1. Desirable stream to use.
2. Time required to apply water.

Answer:
1. The recommended unit stream for a slope of 0.5 percent is 0.034 c. f. s. (fig. 15). Multiplying this by the slope factor (fig. 16) shows the unit stream recommended for a 1.0-percent slope to be 0.0292 c. f. s. (0.034×0.86). The stream required per foot of width for a 440-foot run is 0.0292×4.4, or 0.128 c. f. s. With a slope of 1.0 percent, however, the maximum allowable stream is 0.060 c. f. s. per foot of border width (table 3). Therefore, the field should be irrigated in two runs, using 1.28 c. f. s. border streams ($2.2 \times 20 \times 0.0292 = 1.28$).

A unit stream of 0.0292 c. f. s. will apply 2 inches depth of water in 9.5 minutes (fig. 21). Assuming an application efficiency of 65 percent, the water needs to be run on the border strip for only about 15 minutes.

Sprinkler Irrigation

Sprinkler irrigation is used for almost all crops and on nearly all soils. It may be the only way that crops can be irrigated satisfactorily on soils having a very high intake rate, steep slopes, shallow soils, or irregular topography.

This section suggests a method to gather data on sprinkler equipment and field operating conditions, and to analyze established systems. It should be helpful in working out needed adjustments in design, installation, and operation. It should lead also to developing better sprinkler design criteria for local soils, crops, and climate.

General Performance Requirements

Seven main factors should be checked in any revolving-head sprinkler system to determine adequacy of design and operation, and what adjustments in layout or use may be needed.

1. *Application rate:* Water should not be applied faster than the soil will absorb it. Yet, it should be applied fast enough to prevent excessive evaporation losses.

2. *Depth of application:* The amount of water applied during an irrigation should not be greater at the point of lightest application than can be held by the soil within the root zone of the crop. Greater amounts should be applied only when leaching to remove harmful salts is necessary.

3. *System capacity:* The equipment should be able to replenish the soil moisture at a rate at least equal to the peak rate of use by the crop.

4. *Uniformity of application:* Water should be applied as uniformly as practical over the field. The point of lightest application usually should have received at least 80 percent as much water as the average for the field. Uniformity of application is affected by differences in the discharges of individual sprinklers along a lateral and on different laterals. It also is affected by the uniformity of spray distribution within the effective area of individual sprinklers.

5. *Water losses:* The greatest water loss in a well-designed and operated sprinkler system occurs through wind drift and evaporation between the sprinkler nozzle and the ground. Drop sizes and application rates affect these losses. For efficient water use, such losses should not be more than 10 to 15 percent of the flow through the system.

6. *Economical pipe sizes:* Distribution-pipe sizes should be such that there is an economic balance between pipe cost and power cost.

7. *Crop damage:* Water must be applied in a way that will not damage the crop physically.

Method

The following procedure is suggested for use in checking a sprinkler-irrigation system:

1. Determine the water-distribution pattern in the effective area between two sprinklers on a lateral.

2. Determine the amount of water needed to refill the soil in the root zone.

3. Make an inventory of the sprinkler-system parts and determine the operating procedure.

4. Field check the operating characteristics of the system.

5. Analyze the data obtained.

6. Make recommendations for revision of the system or changes in operating procedures, if necessary.

Equipment Needed for Field Tests

The following items are generally required for the field evaluation of a sprinkler system:

1. Pressure gage (0 to 100 pounds) with pitot-tube attachment to measure pressure at the sprinkler nozzles.

2. Soil auger and shovel.

3. Stopwatch and regular watch or clock.

4. Calibrated container to measure the discharge from individual sprinklers (1- to 5-gallon capacity, depending on the size of sprinkler).

5. Two pieces of rubber garden hose about 4 feet long.

6. About 50 spray gage cans (quart oilcans, or other cans tall enough to catch the maximum application).

7. Graduate to measure the water caught in the spray gage cans (500 cc. capacity graduated to 10 cc.).

8. Chain or tape (100 ft.).

9. Forms for recording data.

Procedure

The order to be followed in evaluating sprinkler-system performance can be varied, but the following step-by-step procedure is suggested:

Refill capacity of soils

Examine the soil in the root zone before the sprinkler test, so that the amount of soil moisture to be added can be estimated.[5] Determine by excavation if necessary the depth of the root zone of the crop. If the crop is not mature, estimate the depth of penetration by the roots of the mature plants.

Inventory and determine operating procedure

Obtain and record data on sprinkler-system design and operation. Use a sheet similar to figure 29 as a checklist and to record the data.

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[5] It is assumed that trial run will be made at the time the crop is in need of irrigation. If the test is made when the soil is wet, the amount of water that would normally be required for an irrigation will need to be estimated.

Most of the information can be obtained from the farmer and by field observations of the equipment.

Water-distribution pattern

Set up sprinkler lateral ready to operate, and set out the spray cans in symmetrical pattern across the lateral between two sprinklers. The cans should be about 5 feet apart where the sprinkler spacing is less than 30 feet, and about 10 feet apart where sprinklers are 30 feet or more apart (fig. 22). The area selected must be far enough from end of the sprinkler lateral to obtain the normal overlapping of the wetted circles from adjacent sprinklers. Set cans level and an inch or two into the ground so they will not be overturned (fig. 23). On sodded areas, it may be desirable to support the cans with short stakes. In tall-growing crops, they should be supported above the vegetation.

Prevent the sprinklers on each side of the spray-gaging area from turning when the water is first turned on so the initial jets from the nozzles will not fall into the measuring cans. After normal operating pressure has been built up in the system, measure and record the pressure and discharge of the sprinklers on each side of the spray-gaging area and the first and last sprinkler on the lateral. Volumetric measurements of discharge may be
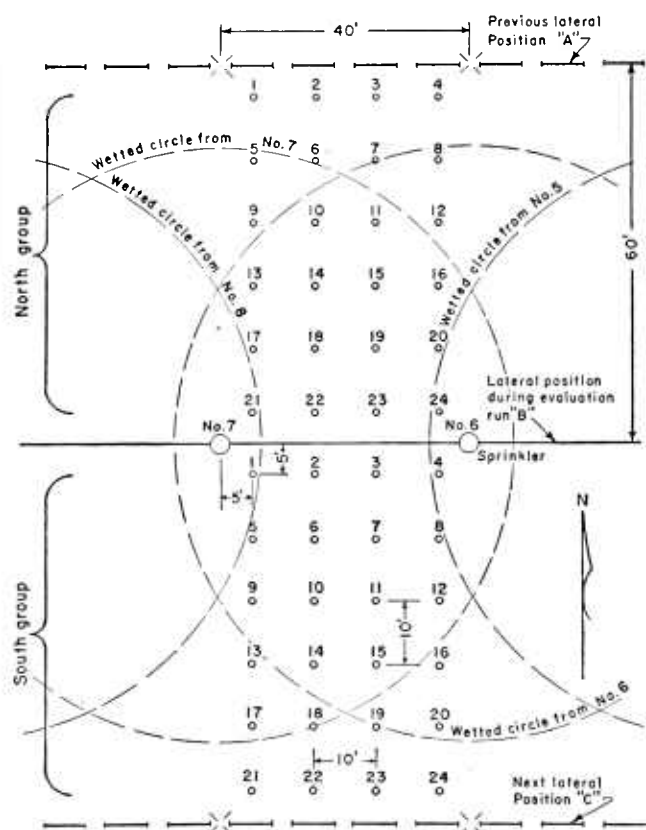

Figure 23.—Method of setting spray gage cans.


Figure 22.—Spray gage can layout.

made by placing a hose over the nozzle and directing the water into a calibrated container (fig. 24). Gallon containers are adequate for discharges up to 10 g. p. m. Use larger ones on sprinklers of greater capacity.

Release the sprinklers after the measurement, recording the time of release. Run the system until a substantial depth of water (usually ½ inch or more) has been caught in the spray gage cans midway between successive lateral positions, but not long enough to cause overflow from any can. Normally, the longer runs provide the more nearly accurate data. For convenience in computations, cut off the test run on the hour.

Stop the sprinklers so that no more spray can fall into the cans. Record the time of stopping and again measure pressure and discharge of the sprinkler on each side of gaging area. Then turn off the water, measure the catch in spray gage cans, and record the measurements. Volumetric measurements with a graduate are faster and more nearly accurate than direct depth measurements with a ruler. Quart-size oilcans hold almost 200 cc. per inch of depth. Readings to the nearest 10 cc., then are equivalent to 0.05-inch accuracy.

System operating characteristics

With the sprinkler system in operation, measure lateral and main-line pressures at various points. Measure the pressures in the lateral pipelines at
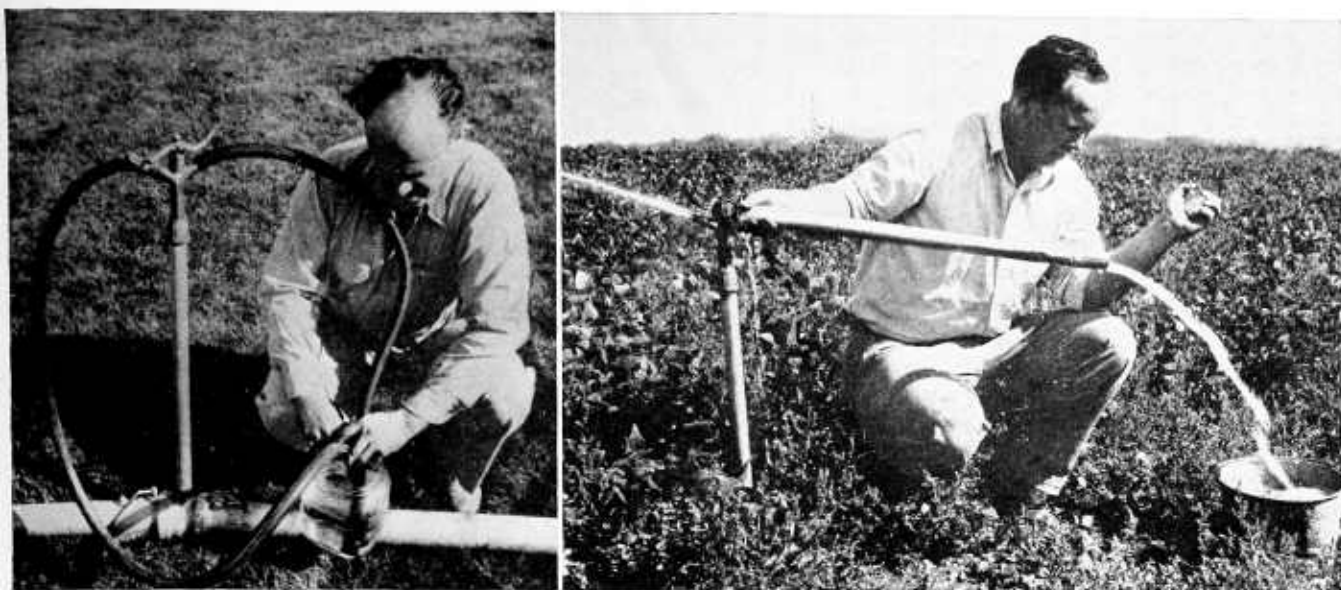
Figure 24.—**Methods for measuring sprinkler discharge: (Left), method for measuring small flows. (Right), method for measuring larger flows. Both nozzles have to be measured to get total discharge.**

first sprinkler from the main-line outlet, the high point in the lateral line, and at the end sprinkler. When feasible, measure the main-line pressure at the pump, at the highest point and at the point farthest from the pump. If a pitot-tube attachment is used, pressures are measured at the nozzles of the sprinklers (fig. 25). Otherwise, pressure gages should be connected into pipelines before water is turned on. Operating costs are lowest and application of water is most nearly uniform when pressures differ little between the various points.

Observe the rate at which water enters the soil, especially in areas around the fastest filling spray gage cans. Water applied at any point at one revolution of the sprinkler should have disappeared before water again is applied to that point. There should be no movement of water over the surface, and more than the slightest ponding is generally unsatisfactory. Intake observations usually should be made after the sprinklers have been operating for several hours. The area wet during the preceding lateral setting often has a lower intake rate than the dry area. Surface movement of water on either area is indicative of too high an application rate.

Determine the adequacy of irrigation by checking, with a soil auger, the depth of water penetration on an area from which the sprinkler lateral had been moved long enough for the water to distribute itself in the soil.

Check for crop damage caused by sprinkling. Such damage may be caused by drop impact, unfavorable jet trajectory, or inadequate riser height.

Note wind direction and estimated or measured velocities, temperature, and humidity.

Record all observations.

Analysis of data

Overall adequacy of the system and needed adjustments in design or operation can be determined by a careful analysis of the field data.

1. *Minimum interval between irrigations*: Divide the depth of water in inches to be applied at each irrigation by the peak consumptive-use rate of the crop. When peak rates are not known, these average values may be used in estimating minimum intervals:

Hot climate_____ 0.30 to 0.35 inch per day
Moderate climate__ .25 to .30 inch per day
Cool climate_____ .20 to .25 inch per day

Local data should be used when available.

2. *Pattern efficiency*: Determine this from the spray-gage-can records. These records, however, show the depths of water caught during only one lateral setting and do not take into account the overlapping that would occur from adjacent lateral settings. An additional run must be made or the records adjusted to show depths that would be caught during a complete irrigation. The area covered by the "south group" of gages (fig. 22) will receive water from the lateral in both positions "B" and "C." Water distribution to the "south group" of gages from position "C" can be assumed to be the same as was measured in the "north group." Thus, records for the "north group" can be superimposed on those for the "south group" to obtain the total-depth-of-
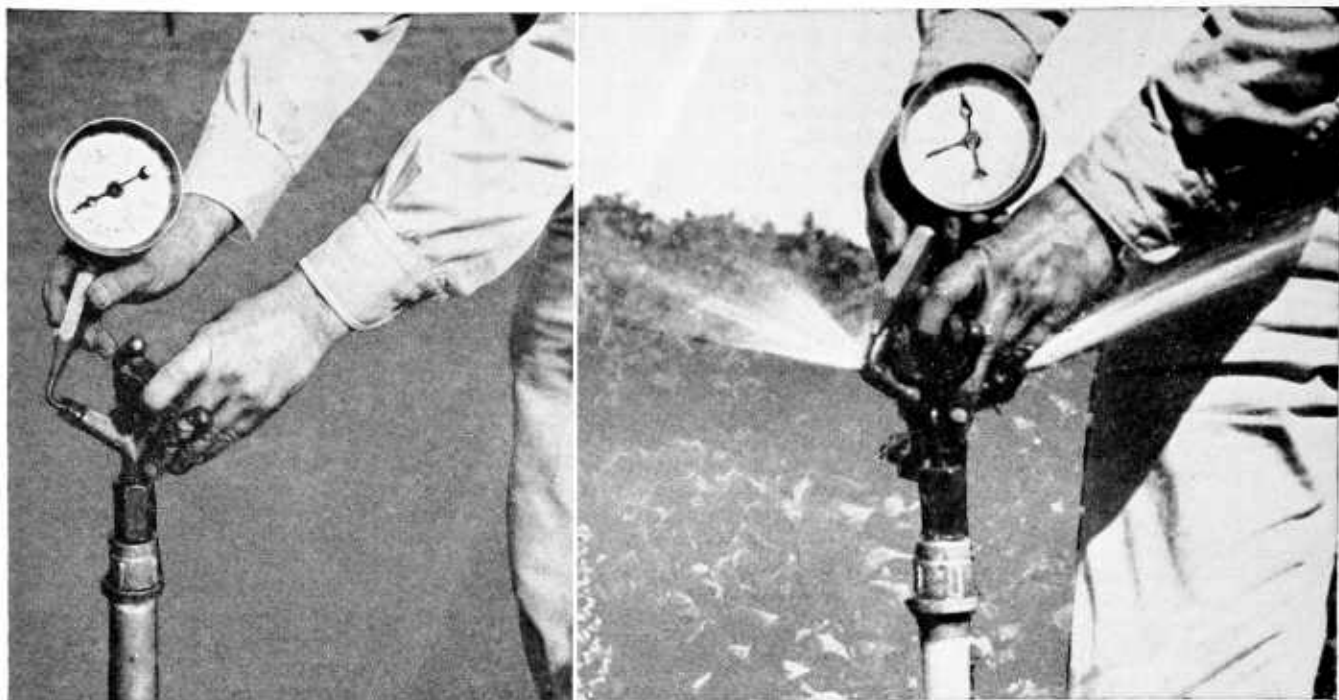
Figure 25.—Using pressure gage with pitot tube to measure pressure. (Left), tip of pitot tube must be centered in water jet, and must be held parallel with center of jet. (Right), hold about one-eighth-inch from nozzle and twist into position, observe gage for maximum reading, which will occur when pitot tube is properly positioned.

application values for that area. "North group" gage records must be kept in their proper position relative to lateral position "C," so that all water caught in gages having the same number can be added together for an adjusted catch.

Divide the sum of the adjusted depths in the "south group" by the number of gages in that group to get the average depth of catch.

Inspect the adjusted gage records for minimum depth of catch. Since the value at any one gaging site may be affected by experimental errors, it is best to use as the minimum the average for the 25 percent of the gages having the least adjusted water depths.

Divide the minimum depth of catch by the average depth of catch for the area to determine the pattern efficiency.

3. *Water losses:* Subtract the average depth of water reaching the ground, as measured in the spray gage cans, from the average depth of application as calculated from the discharge of the sprinklers on each side of the gaging area. Convert the sprinkler discharge to average depth as follows:

$$\frac{\text{Inches}}{\text{depth}} = \frac{\text{Gallons per minute x 96.3 x hours operated}}{\text{Sprinkler spacing (ft.) x lateral spacing (ft.)}}$$

4. *Application efficiency for the gaged area:* Divide the minimum depth of catch by the average depth discharged from the sprinkler nozzles adjacent to the gaging area.

5. *Application efficiency for the lateral:* Divide the minimum depth of catch by the computed depth for the average discharge of all the sprinklers on the lateral. Since sprinkler discharge is a function of pressure, differences of over 20 percent in pressures along the lateral generally result in unsatisfactory lateral efficiencies.

When the discharge of each sprinkler on the lateral is not measured, the average is considered to be the discharge of the first sprinkler minus three-fourths of the difference between first and last sprinklers.

6. *System efficiency:* If lateral pressures can be maintained about the same for all settings, lateral efficiency and system efficiency can be considered identical. If lateral pressures vary at different settings, however, additional evaluation trials may need to be made to determine overall system efficiency.

7. *Time required for each lateral setting:* Divide the inches depth of water required to fill the root zone by the average depth caught per hour in the area of minimum application

8. *Number of lateral moves per day:* Divide 24 hours by the required hours of operation plus the time required to move the lateral. If system is not operated on a 24-hour day basis, use total operating and moving time available per day.

9. *Number of days to cover field:* Divide total number of lateral moves needed to cover the field

by the product of the number of lateral moves per day and the number of laterals

10. *Sprinkler-system capacity:* Multiply the maximum number of sprinklers in operation by the average sprinkler discharge in gallons per minute.

11. *Pump pressure head:* Multiply the pressure in pounds per square inch, measured at the pump, by 2.31 and add the difference in elevation in feet between the pump and the water level on intake side of pump.

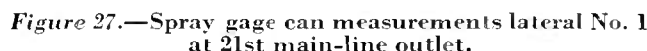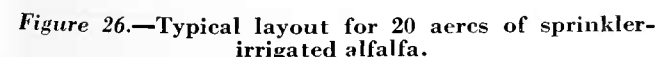## Conclusions and recommendations

The calculations and operation inventory give a basis for conclusions as to the adequacy of design and effectiveness of operation and recommendations for improvements.

Sample Analysis

A sprinkler system in a moderately cool climatic area is evaluated to illustrate the application of the procedure and methods of analyzing the field data.

This system irrigates a rectangular 20-acre field of alfalfa which has a peak-use rate of 0.25 inch per day. Water is pumped from a well midway along the north side. Two sprinkler laterals operate from the buried main pipeline, which is along the centerline of the field (fig. 26).

Both laterals have the same size pipe and sprinkler nozzles. Lateral No. 1, at the 21st pipeline outlet from the pump, was selected for evaluation.

Refill capacity of soil

The soil is a coarse-textured sandy loam from 0 to 36 inches and a light-textured fine sandy loam from 37 to 72 inches. The average total available water-holding capacity of the 6-foot profile was 6.0 inches. Before irrigation, the profile contained 3.1 inches of available moisture, so 2.9 inches had to be added by irrigation.

Figure 26.—Typical layout for 20 acres of sprinkler-irrigated alfalfa.

Figure 27.—Spray gage can measurements lateral No. 1 at 21st main-line outlet.

Water-distribution pattern

The water-distribution pattern for the lateral between the 6th and 7th sprinklers was determined, using spray gage cans. The sprinkler lateral was run 4 hours for this test. Figure 27 shows location and amount of water caught in each spray can, and the computed average depth per hour.

Inventory and operating procedure

Items 1 to 5, figure 28, give data on the sprinklers, pipeline, pump, and water source, gathered in field observations. Item 6 tells how the farmer operates his sprinkler system

System operating characteristics

Pressure and discharge measurements taken at sprinklers 1, 6, 7, and 8 on lateral No. 1 are recorded in figure 29. The average of the two discharge measurements on each sprinkler is 9.5, 8.9, 8.7, 8.6 g. p. m., respectively.

Observation showed the soil was taking the water satisfactorily, with no water movement over the surface or ponding. The maximum rate of application was found to be 0.34 inch per hour (fig. 27).

Adequacy of irrigation was checked on an area from which the sprinkler lateral had been moved 24 hours earlier. The root zone was filled to capacity.

There were no signs of crop damage caused by sprinkling.

Analysis of data

1. *Minimum interval between irrigations:* The peak consumptive-use rate of alfalfa in this area is 0.25 inch per day. The moisture to be replaced is 2.9 inches. Therefore, the minimum interval between irrigations will be

$$\frac{2.9}{0.25} = 11.6 \text{ (use 11 days).}$$

2. *Pattern efficiency:* Figure 30 shows the water-distribution pattern, determined from the spray gage measurements. Since the gages are located in a uniform pattern, the average depth of application over the gaging area equals the sum of the depths (7.33 inches) divided by the number of gage cans (24), or 0.305 inch.

The minimum depth, or the average of the catch in 6 cans, is 0.250 inch.

$$\frac{0.22 + 0.25 + 0.25 + 0.25 + 0.25 + 0.28}{6} = 0.250$$

Pattern efficiency is $(0.250 \div 0.305) \times 100 = 82$ percent, which indicates good sprinkler perform-ance. It is necessary to apply an average of 3.5 inches $(2.9 \div 0.82 = 3.5)$ to supply at least 2.9 inches of water to all parts of the field.

3. *Water losses:* The average discharge of sprin-klers 6 and 7 was 8.8 g. p. m., equivalent to a depth of application of 0.354 inch per hour for a 40 x 60-foot spacing. Since the average depth of application in the spray gages was 0.305 inch, the loss between the nozzles and the gages was 0.049 inch, or nearly 14 percent. Probably only a part of this loss is evaporation and wind drift, since some splash may have occurred and the average catch in the gage cans may have been slightly lower than the average depth applied over the ground surface. In any case, a loss of 14 percent is not unreasonably high.

4. Application efficiency for the gaged area is the minimum depth of application (0.250 inch) divided by the average depth of application measured at the nozzles (0.354 inch) $\times$ 100, or 71 percent. This is satisfactory.

5. *Application efficiency for the lateral:* The application efficiency of lateral No. 1 is the min-imum depth of application (0.250 inch) divided by the depth of application (computed for the average sprinkler discharge on the lateral) times 100. The average sprinkler discharge is 9.5— $\frac{3}{4}(9.5 - 8.6) = 8.8$ g. p. m.

As the average discharge for all sprinklers on the lateral is the same as the measured discharge of the two sprinklers adjacent to gaging area, the appli-cation efficiency for the lateral is the same as the efficiency computed for the gaging area.

Farm __Joe Urban__ Location __Caribou SCD__ Date __August 1, 1951__

Field No. __1__ Acres __20__ Crop __Alfalfa__

1. SPRINKLER INFORMATION: Make __Rainbird__ Model __40__ Number of nozzles __2__
   Nozzle size __3/16" & 1/8"__ Rated discharge __85__ g. p. m. at __35__ lbs. pressure

2. SPRINKLER LATERALS: Number of laterals __2__ Number of sprinklers per lateral __8__
   Sprinkler spacing __40__ ft. Distance moved __60__ ft. Riser height __1__ ft.
   Lateral No. 1 __300__ ft. __2__ in. diameter and _____ ft. _____ in. diameter
   Lateral No. 2 __300__ ft. __2__ in. diameter and _____ ft. _____ in. diameter
   Lateral No. 3 _____ ft. _____ in. diameter and _____ ft. _____ in. diameter

3. MAIN-LINE PIPES: Number of outlet valves __22__ Spacing of valves __60__ ft.
   Size __1,300__ ft. __4__ in. diameter _____ ft. _____ in. diameter _____ ft. _____ in. diameter

4. PUMP: Make __Ingersoll-Rand__ Model No. __2-CRVNL__ Serial No. __01496483__
   Capacity __150__ g. p. m. at __150__ ft. head. Type power __Electric__
   Horsepower __7-1/2__ r. p. m. __3,460__ Elevation pump to water level __40__ ft.

5. WATER INFORMATION: Source __Well__ Quantity __200__ g. p. m.
   Delivery schedule __Continuous__

6. OPERATIONS: Number of lateral moves to cover field __44__
   Number of moves per day __2__ Number of laterals operating __2__
   Hours sprinklers operated each day __11-1/2__ Hours to move lateral _____
   Maximum number of sprinklers operating __16__ Minimum number of sprinklers operating __16__

7. REMARKS: __First year in alfalfa. Last 3 years row crops.__

Figure 28.—Sprinkler-system design and operation.

Time sprinklers started __10:30__ a. m.   Time sprinklers stopped __2:30__.

Duration of test run ____4____ hours.

Wind direction ____NE____.   Estimated velocity ____5____ m. p. h.

Temperature __90-95__ degrees.   Humidity ____Low____.

Main-line pressure at pump __45__ p. s. i.   At high point in field __42__ p. s. i.

At end of main line __42__ p. s. i.

Water-application rate observations __Rate satisfactory--Maximum 0.34 in./hr.__

Sprinkler pressure and discharge measurements

Time	Sprinkler No. 1			Sprinkler No. 6			Sprinkler No. 7			Sprinkler No. 8			Sprinkler No.		
	Pressure lbs./sq. in.	Time to fill container--sec.	Discharge g. p. m.	Pressure lbs./sq. in.	Time to fill container--sec.	Discharge g. p. m.	Pressure lbs./sq. in.	Time to fill container--sec.	Discharge g. p. m.	Pressure lbs./sq. in.	Time to fill container--sec.	Discharge g. p. m.	Pressure lbs./sq. in.	Time to fill container--sec.	Discharge g. p. m.
Lateral No. 1															
10:20	42	6.3	9.5	37	6.7	9.0	36	6.9	8.7	35	7.0	8.6			
2:35	42	6.4	9.4	37	6.8	8.8	36	6.9	8.7	35	7.0	8.6			
Lateral No. 2															
1:00	44									37					

Capacity of calibrated container __1.0__ gallons

Figure 29.—Field-evaluation data.

Lateral

Sprinkler	0.34 / .01 / 35	0.32 / .00 / .32	0.31 / .00 / .31	0.28 / .00 / .28
Spray-gage cans	0.20 / .02 / .22	0.23 / .02 / .25	0.30 / .02 / .32	0.24 / .01 / .25
Catch per hour from south can / Catch per hour from north can / Adjusted catch per hour	0.22 / .09 / .31	0.23 / .09 / .32	0.23 / .10 / .33	0.23 / .11 / .34
	0.11 / .22 / .33	0.09 / .16 / .25	0.11 / .20 / .31	0.12 / .23 / .35
	0.04 / .28 / .32	0.03 / .22 / 25	0.02 / .29 / .31	0.03 / .30 / .33
	0.00 / .34 / .34	0.01 / .30 / .31	0.00 / .31 / .31	0.00 / .32 / .32

Lateral

5' — 10' — 10' — 10' — 5'
40'

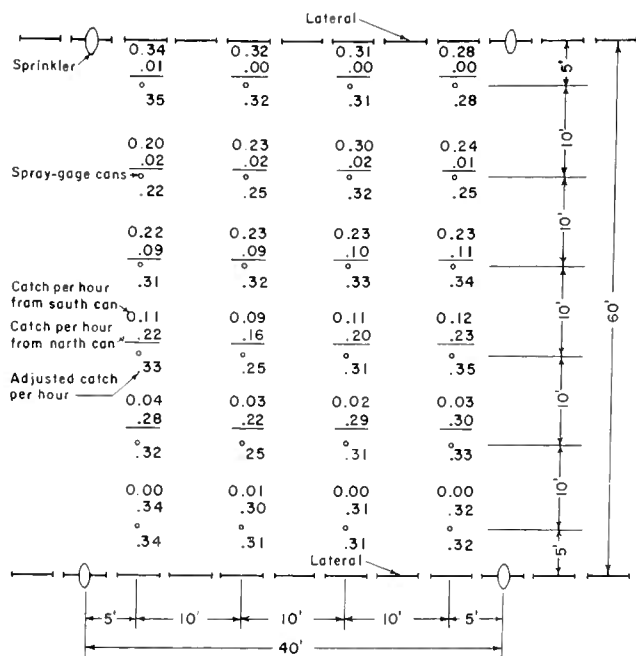(vertical dimensions: 5', 10', 10', 10', 10', 5' = 60')

Figure 39.—Water-distribution pattern on sample area.

On longer laterals, the average sprinkler discharge is usually greater than the discharge of the two sprinklers near the end of the lateral. Here application efficiency of the lateral would be lower than for the gaging area.

6. *System efficiency:* Since the main line in this example is equipped with takeout valves, operating pressures can be maintained approximately equal for all lateral positions. The overall system efficiency, therefore, is considered equal to the efficiency at lateral No. 1.

It should be noted that with split-line operation, as in this example, operating pressures may be lowest when the laterals are opposite each other in the center of the field. This will always be true when a uniform size main is used and laid on a uniform grade. When this condition is found, the evaluation trial should be made at a lateral setting near the center of the field. Due to topographic conditions, the minimum operating pressure in this system was at the far end of the main line.

7. *Time required for each lateral setting:* The time required to apply the net 2.9 inches of water to fill the soil profile to field capacity will be 11½ hours (2.9÷0.25).

8. *Number of lateral moves per day (24 hours):* With 11½ hours' operating time and ½ hour to move the lateral, there can be two moves per day.

9. *Number of days to cover field:* Forty-four lateral settings are needed to cover the field. Each of the 2 laterals is moved twice a day thus making 4 sets per day. The number of days required will be 44÷4=11.

10. *Sprinkler system capacity:* Average sprinkler discharge for lateral No. 1 was 8.8 gallons per minute. The discharge of sprinklers on lateral No. 2 was not measured, but the manufacturer's rated discharge for the average pressure as computed from pressure measurements in figure 29, was 9.0 g. p. m. System capacity must be: (8.8×8)+(9.0×8)=142.4 g. p. m.

11. *Pump pressure head:* (45×2.31)+40=144 feet.

Conclusions and recommendations

This system is well designed, with equipment capable of meeting crop requirements in peak-water-use periods. Application rate is satisfactory for the soils. The water-distribution pattern is reasonably uniform. Lateral and main pipelines are adequately designed for efficient operation costs. The capacity of the pump is adequate.

Operation of the system is satisfactory, but the equipment will just meet the peak-use requirements. The peak-use frequency is 11 days and the field can be irrigated in 11 days. This leaves no safety factor for breakdowns or other interruptions during the peak-use period. In the off-peak periods, however, when the rate of water used by the crops is less, the system need not be operated continuously.